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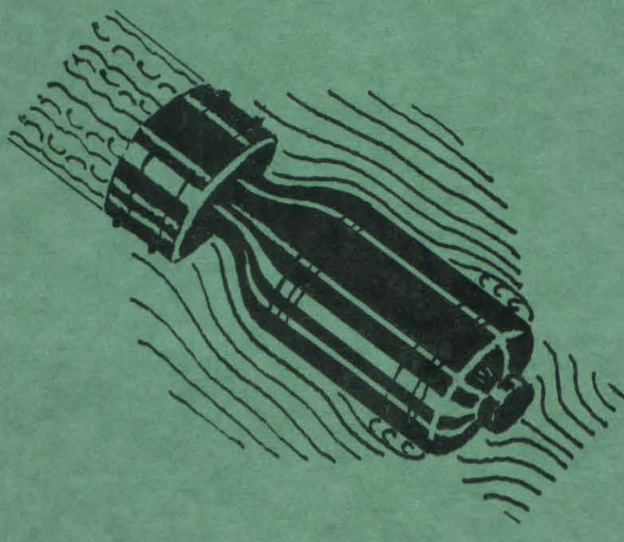
WATER TUNNEL TESTS OF THE MK 25 TORPEDO WITH GAS EXHAUST THROUGH A HORIZONTAL PIPE



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

SECTION № 6.1 - SR-207-1640
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WATER TUNNEL TESTS
OF THE
MK 25 TORPEDO
WITH A
HORIZONTAL EXHAUST PIPE

BY

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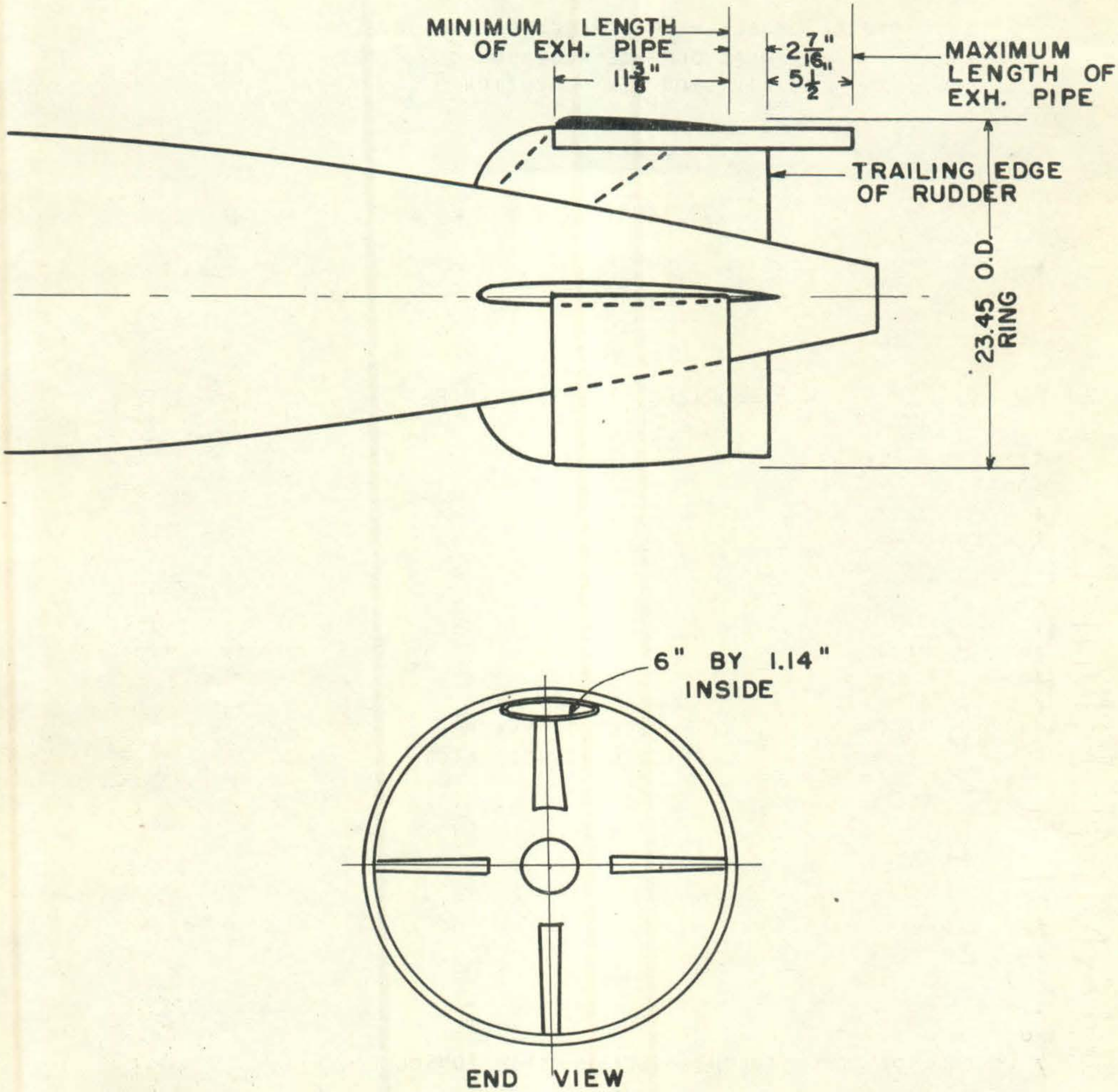


DETAILS OF EXHAUST PIPE

FIGURE 1

WATER TUNNEL TESTS

OF THE

MK 25 TORPEDO

WITH

GAS EXHAUST THROUGH A HORIZONTAL PIPE

GENERAL

This report covers tests made on the MK 25 torpedo to determine the effect of gas discharged through a horizontal exhaust pipe. This report is supplemental to the report, Section No. 6.1-sr207-1275, which described tests with the gas discharged through a vertical fin. It was requested by Dr. E. H. Colpitts, Chief of Section 6.1 NDRC, in a letter dated May 4, 1944. The objective of both this and the former report is to examine the effects of discharging the turbine exhaust gases through the fin structure instead of through the propeller shafts. Since the feasibility of this new method of exhaust discharge is greatly dependent on the effect of the gas flow on the afterbody fin structure and propeller zone, both studies have been restricted to the observation and analysis of this flow. Determination of the effects of the discharge passages and gas stream on the hydrodynamic stability, rudder control, and propeller efficiency have been deferred pending the development of an exhaust passage having discharge characteristics that are not visibly unsatisfactory. Several different lengths of exhaust pipe were tested; also, runs were made for various values of velocity and submergence and different amounts of gas discharged. Photographs were taken to show the exhaust cavities created under the different conditions.

All data refer to the prototype unless otherwise stated.

Gas discharges are expressed in per cent. This figure has been calculated with reference to the amount of gas discharged from the prototype when running at 40.5 knots. Allowances for temperature and composition of the exhaust gases have been made by calculating the exit velocity when the torpedo is running at 40.5 knots and 15 feet submergence, computing the ratio of this velocity to that of the torpedo, and then calculating the amount of air required by the model to obtain this velocity ratio when operating at the equivalent submergence. This criterion requires that a different rate of air flow be taken as the 100% amount for each torpedo velocity investigated. However, as in the prototype, the mass rate of gas flow in the model is constant for any given water velocity, independent of the changes in tunnel pressure (i.e., submergence).

Figure 1 gives details of the afterbody used in these tests. The exhaust takes place through an oval shaped exhaust pipe approximately 6" x 1.14" located directly over the vertical fin. The maximum extension of the exhaust pipe was 5.5" beyond the trailing edge of the vertical rudder or to the center of the after propeller.

CAVITATION PARAMETER

The air bubble formed by the discharge of gas from the fin is identical in behavior with the normal cavitation bubble. The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter, K. This parameter is normally defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}}$$

in which

P_L = absolute pressure in the undistrubed liquid, lbs/sq ft

P_B = vapor pressure corresponding to the water temperature lbs/sq ft

V = velocity, ft/sec

ρ = mass density of the fluid in slugs per cu ft = $\frac{w}{g}$

If (P_B) is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, for equal values of K, the behavior of the bubble will be the same whether the bubble is due to cavitation or to the injection of gas as in the present tests.

The chart, Figure 25, shown at the end of this report, gives values of K as a function of velocity and submergence in sea water at a temperature of 50° Fahrenheit. For this chart the pressure in the bubble is assumed to be the vapor pressure for this temperature.

CAVITATION WITH NO EXHAUST

Figures 2, 3, and 4 show the cavitation effects on the model for values of K = 0.56, 0.38, and 0.27 with no gas exhaust. At K = 0.56 (Figure 2), cavitation is well developed at the junction of the nose and the body, also it is seen along the trailing edges of the fins and ring. As the value of K is reduced, the cavitation effects are much more pronounced, as seen in Figures 3 and 4.

The value of K for 40.5 knots and a submergence of 15 feet is 0.67. This represents the normal condition for this projectile. Figure 2 should be kept in mind when considering the exhaust cavities produced with different gas discharges as the small amount of cavitation shown there corresponds to a value of K considerably smaller than that for the normal condition.

FIGURE 2

K = 0.56

FIGURE 3

K = 0.38

FIGURE 4

K = 0.27

CAVITATION FOR VARIOUS VALUES OF K

NO EXHAUST GAS

EXHAUST CAVITIES

Exhaust Pipe 5.5" Long

Figures 5, 6, and 7 show the full length of exhaust pipe with values of K from 0.91 to 0.43 and approximately 50% of the normal volume of gas exhausted.

In analyzing these photographs one apparent anomaly must be understood. The cavitation parameter, K, can be quite different for two cavities existing simultaneously on the same body, *provided* that they are separated and that the gas pressures within the bubbles are different. For pure cavitation this latter condition obviously is impossible, since the bubble pressure can only be the vapor pressure of the liquid, and is, therefore, the same for all cavities existing simultaneously on the body. However, for the case under consideration, the exhaust gas bubble is at a much higher pressure than the vapor pressure of the water. In this bubble the only factor that limits the bubble pressure is the rate at which the gas is entrained and pumped away from the after end of the bubble by the swirling water. In fact the gas pressure will rise to cause the bubble to grow until the entrainment rate balances the rate of inflow from the exhaust passage.

If the expression for the cavitation parameter is re-examined in the light of these coments

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}}$$

it willbe seen that the only item that differs in value between the calculation for the water vapor filled cavitation bubble and the simultaneously existing exhaust gas bubble is P_B, and since this is much larger in the latter case, the corresponding value of K is considerably smaller. These considerations explain the apparent inconsistencies in Figures 5, 6, and 7 and similar subsequent series in which the tunnel velocity is kept constant, while the pressure is dropped to produce reductions in K. In these figures the true cavitation bubbles on the nose and on the ring and fins are seen to increase greatly as K is reduced, while the exhaust bubble shows little change. This is because the effective K for the exhaust bubble changes much less than does the tunnel K. As the tunnel pressure lowers, the exhaust pressure lowers at nearly the same rate, thus keeping K practically constant. The only deviation will be that required to produce the slight increase in bubble size necessary to secure the additional volume of entrainment to balance the increased volume of exhaust which results when the same mass flow is expanded to the lower bubble pressure.

FIGURE 5

K = 0.91 50% EXHAUST

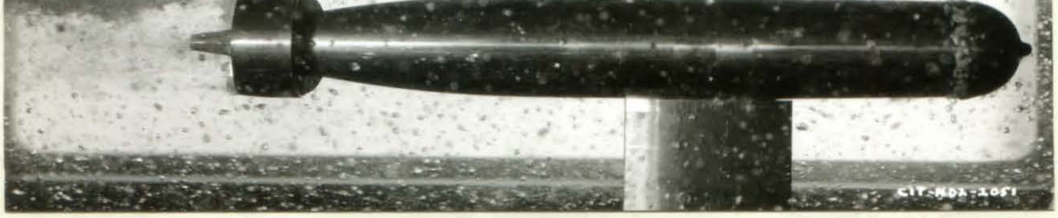


FIGURE 6

K = 0.60 50% EXHAUST

FIGURE 7

K = 0.43 50% EXHAUST

(SAME AS FIGURE 8)

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST PIPE 5.5" BEYOND TRAILING EDGE OF RUDDER

Figures 8, 9, and 10 show the effect of increasing the amount of the exhaust with a practically constant value of K. There appears to be little, if any, increase in the cavitation about the tail with an increase in exhaust gas from 50% to 100% of normal. The cavitation noted immediately adjacent to the ring and fins is not much different from that seen in Figure 3 with no exhaust gas.

Exhaust Pipe 1.45" Long

Figures 11, 12, and 13 show the result of shortening the exhaust pipe so it extends only 1.45" beyond the trailing edge of the rudder. The quantity of exhaust gas was about normal and K was varied from 0.97 to 0.52. In Figure 12, which about corresponds to the normal values of K and volume of gas, it is apparent that the exhaust cavity would cause serious interference with the propellers and a little interference with the rudders. When the value of K is lowered to 0.52, it is seen in Figure 13 that the exhaust cavity has now combined with the cavitation bubble of the ring and fins, which would make the rudders and propellers practically inoperative.

Exhaust Pipe Flush with Edge of Shroud Ring

Figures 14, 15, and 16 show the effect produced with approximately 50% exhaust gas and K varying from 1.02 to 0.47. These pictures clearly indicate how the exhaust cavity is drawn into and combines with the cavitation bubble formed by the tail.

In Figure 15, which illustrates the condition for the normal value of K, the exhaust cavity extends practically to the center of the torpedo, which would seriously impair the operation of the rudders and propellers.

The effect of varying values of K for practically 100% exhaust gas is shown in Figures 17, 18, and 19. Comparing this series with that mentioned above, for the same values of K and 50% exhaust, it is seen that doubling the volume of the exhaust causes little change in the size of the exhaust cavity. The greatest difference in corresponding pictures in the two series is between Figures 16 and 19. The exhaust cavity for 100% exhaust combined with the cavitation bubble is more pronounced than it is with 50% exhaust. However, in both cases the cavity extends around the entire circumference of the ring tail, completely enveloping the rudders and propellers.

Attention is called to the air bubbles appearing quite generally throughout the tunnel in Figures 6, 7, 9, 10, and 23. These are bubbles from the exhaust that have reappeared in the working section after traveling completely around the tunnel circuit. They have no significant influence on the behavior of the exhaust jet itself.

FIGURE 8

K = 0.43 50% EXHAUST

(SAME AS FIGURE 7)

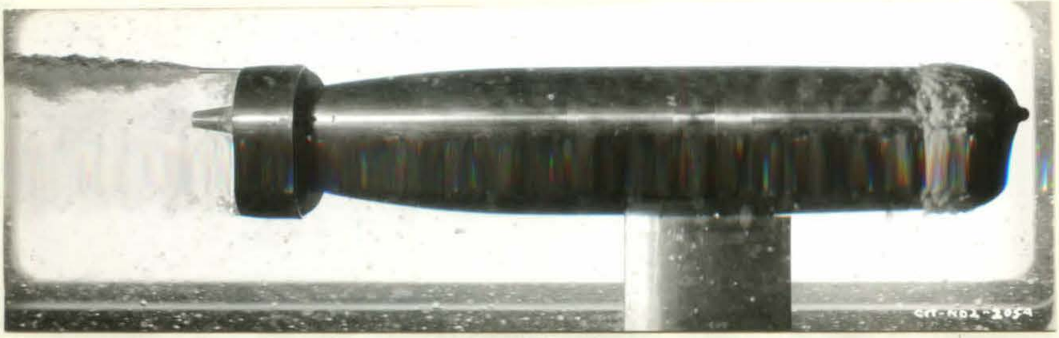


FIGURE 9

K = 0.48 75% EXHAUST

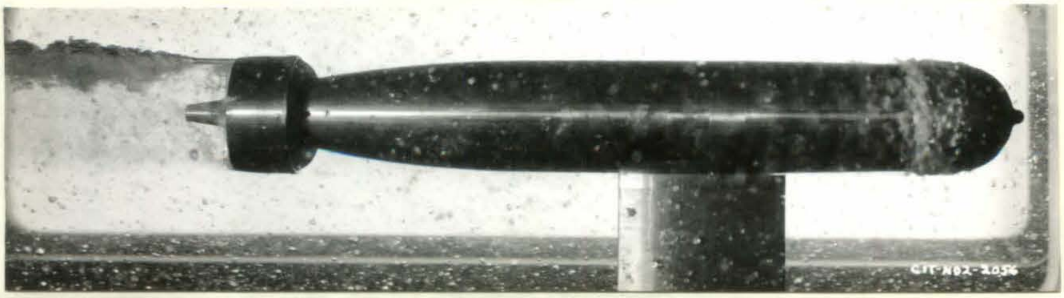


FIGURE 10

K = 0.46 100% EXHAUST

EXHAUST CAVITIES FOR VARIOUS QUANTITIES OF EXHAUST GAS

EXHAUST PIPE 5.5" BEYOND TRAILING EDGE OF RUDDER

FIGURE 11

K = 0.97 100% EXHAUST

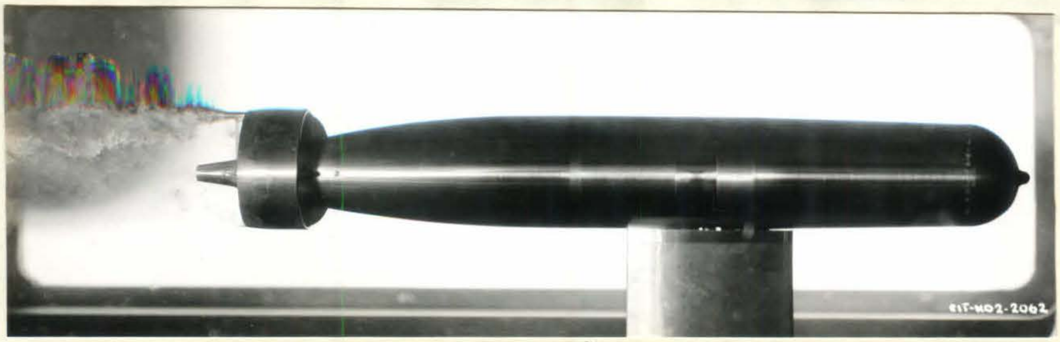


FIGURE 12

K = 0.71 100% EXHAUST

(SAME AS FIGURE 22)

FIGURE 13

K = 0.52 100% EXHAUST

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST PIPE 1.45" BEYOND TRAILING EDGE OF RUDDER

FIGURE 14

K = 1.02 50% EXHAUST

FIGURE 15

K = 0.69 50% EXHAUST

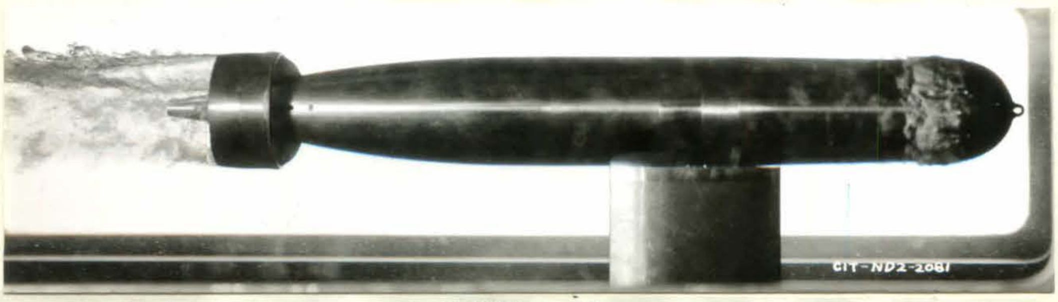


FIGURE 16

K = 0.47 50% EXHAUST

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST GAS 50% OF NORMAL

EXHAUST PIPE FLUSH WITH TRAILING EDGE OF SHROUD RING

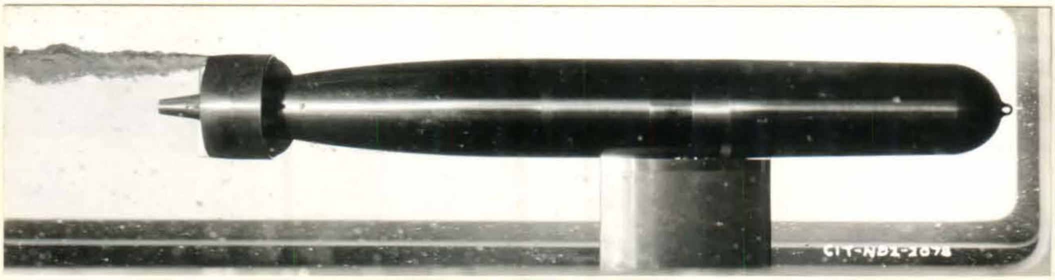


FIGURE 17

K = 1.02   75% EXHAUST

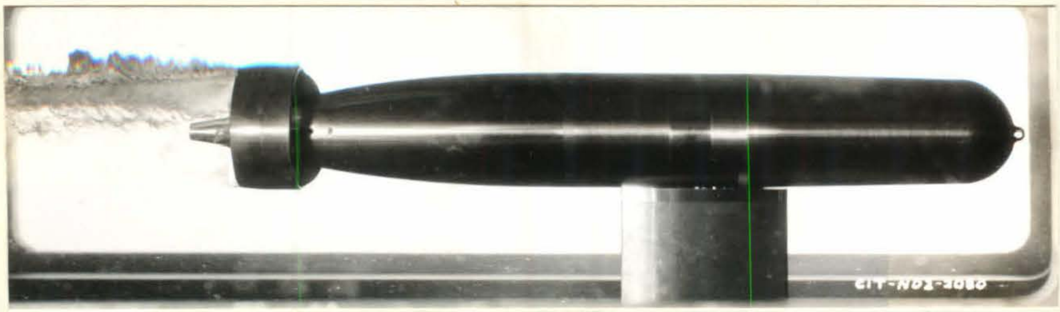


FIGURE 18

K = 0.71   100% EXHAUST

(SAME AS FIGURE 24)

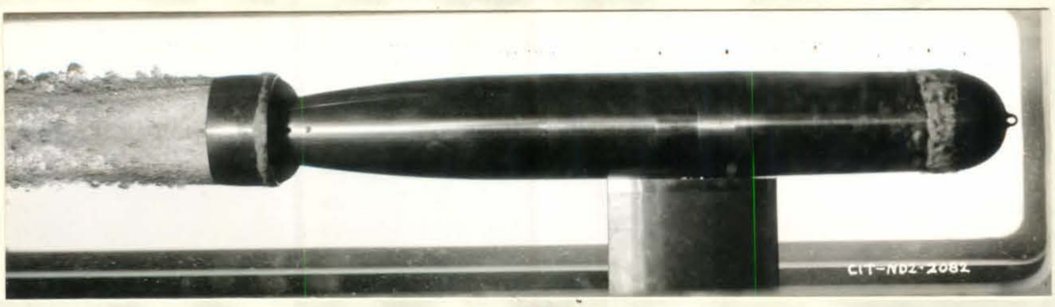


FIGURE 19

K = 0.46   100% EXHAUST

EXHAUST CAVITIES FOR VARIOUS VALUES OF K

EXHAUST PIPE FLUSH WITH TRAILING EDGE OF SHROUD RING

FIGURE 20 K = 0.68 100 % EXHAUST

FIGURE 21 K = 0.68 100 % EXHAUST

FIGURE 22 K = 0.71 100 % EXHAUST
(SAME AS FIG. 12)

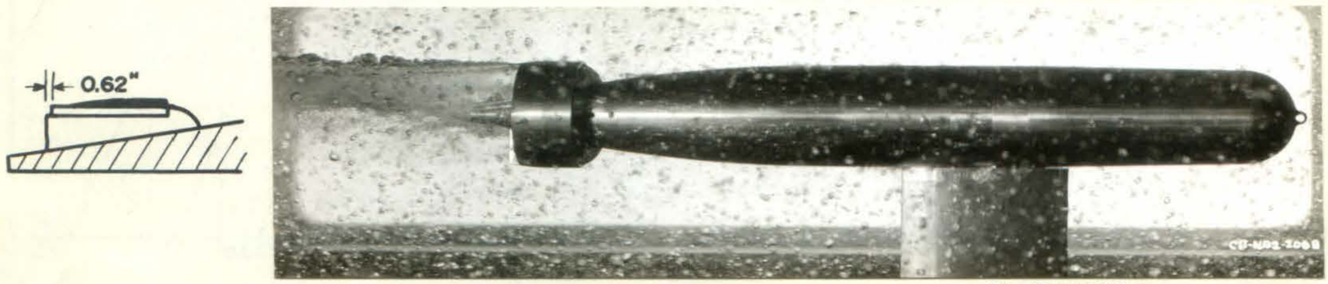


FIGURE 23 K = 0.76 100 % EXHAUST

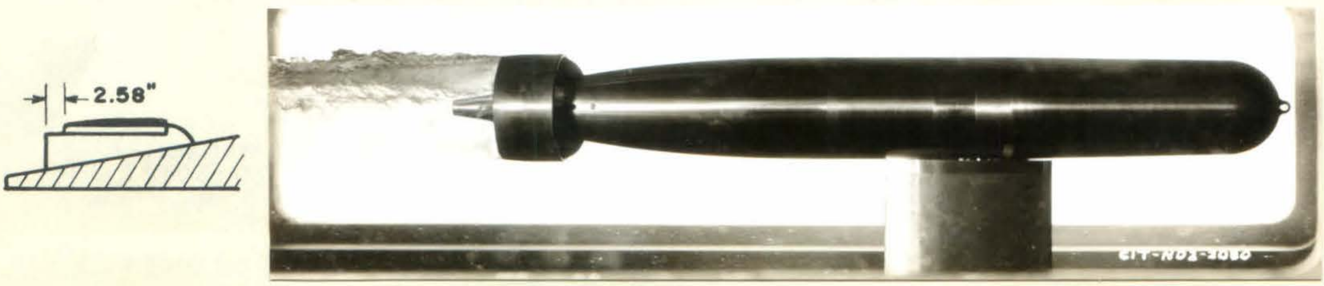
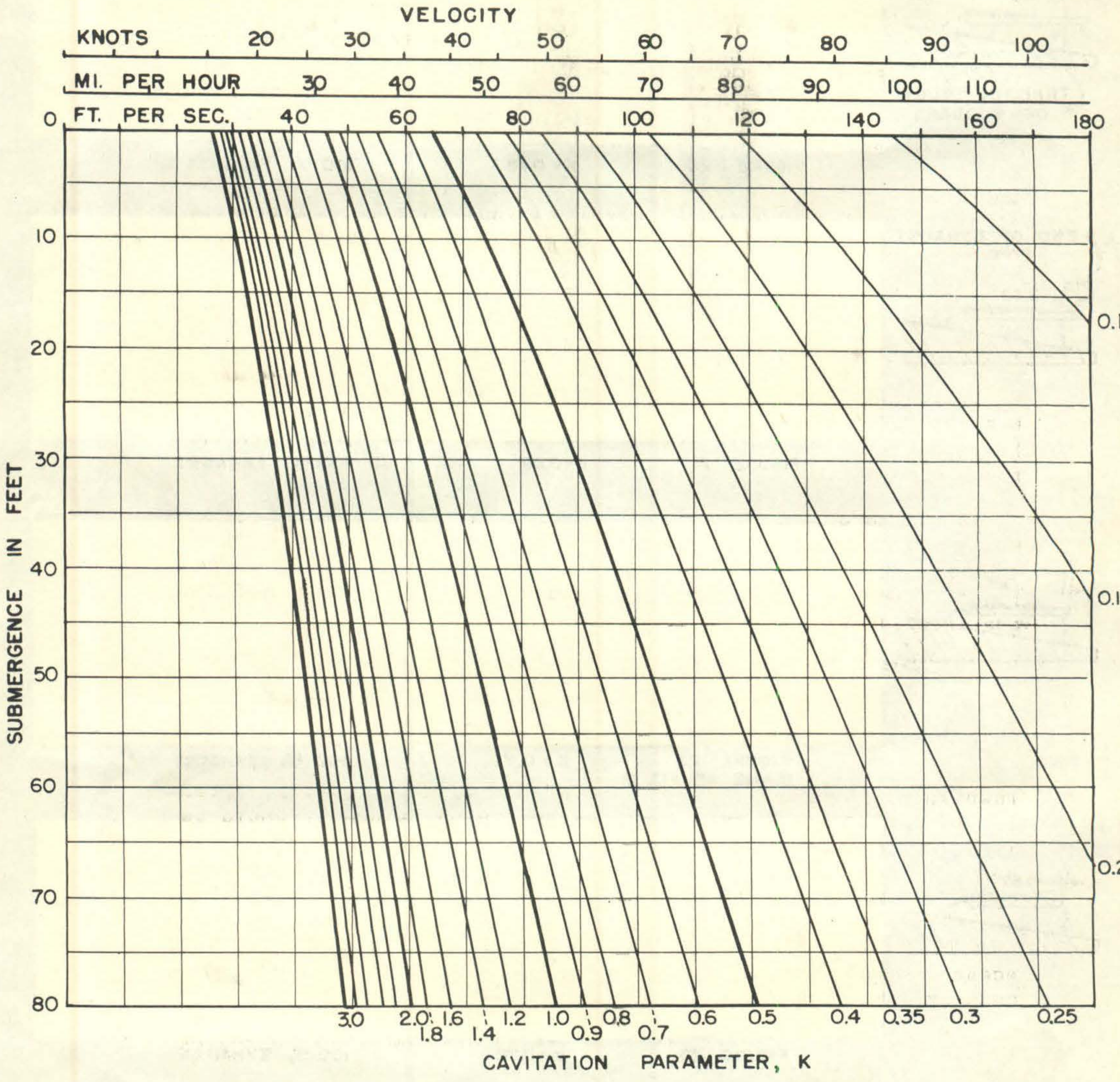


FIGURE 24 K = 0.71 100 % EXHAUST
(SAME AS FIG. 18)

EXHAUST CAVITIES FOR VARIOUS
LENGTHS OF EXHAUST PIPE



RELATION BETWEEN VELOCITY SUBMERGENCE AND CAVITATION PARAMETER, K

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FIGURE 25

CONCLUSIONS

Figures 20 to 24 show the exhaust cavities for the five different lengths of exhaust pipe and under practically normal conditions of velocity, submergence, and quantity of exhaust gas.

It appears, from Figures 20 and 21, that an exhaust pipe extending not less than 3.68" beyond the trailing edge of the rudders would cause practically no interference with the rudder operation. It is possible, however, that this length of pipe would permit the exhaust cavity to be drawn into the propellers.

With the exhaust pipe extending only 1.45" behind the rudders, as shown in Figure 22, there is a decided increase in the cavitation bubble immediately adjacent to the outer trailing edge of the rudder and there are indications that the exhaust cavity is extending into the vicinity of the propellers. With the propellers in operation it is believed that this point of discharge for the exhaust would permit the exhaust cavity to be drawn into the propellers, thus seriously reducing their effectiveness.

When the exhaust takes place *forward* of the trailing edge of the rudders, as shown in Figures 23 and 24, the exhaust cavity, by combining with the cavitation bubble, assumes such proportions that the rudders and propellers would be completely enveloped and made inoperative.

The conclusion must be drawn from these tests that the only exhaust pipe arrangements that give any promise of being satisfactory are the ones shown in Figures 20 and 21, extending 5.5" and 3.68" beyond the rudders. While the tests indicate that these arrangements may possibly guard against the exhaust cavity being drawn into the propellers, there is objection to the long extension of the comparatively small exhaust pipe, since it would be difficult to make it strong enough to prevent damage during water entry or even during handling. A change in the design to eliminate this objection would be desirable and is being explored.

These two series of tests have served to establish one necessary condition that must be fulfilled by any acceptable exhaust system. The exhaust must be discharged into a low pressure region separated from the structure of the projectile by zones of higher static pressure, that is aft of any low pressure region that offers a continuous low pressure path to the fin structure, afterbody, or propeller zones. The gas will flow in the direction of the pressure gradient. This fact explains why it can penetrate across or against the flow of the water in certain cases. This effect is shown in Figures 13 to 19 inclusive, 23 and 24, as well as Figures 5 to 10 and 12 and 13 of the previous report (Section No. 6.1-sr207-1275). All of these figures represent examples of violation of the condition for acceptable discharge explained above.